Laboratory-scale fractionation of distillers dried grains with solubles (DDGS)

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Abstract: The objective of this project was to separate distillers dried grains with solubles (DDGS) into high protein and high fiber fractions, in order to improve the value and utility as a livestock feed. This project used a laboratory-scale cylindrical blower (Iowa blower) and a laboratory-scale gravity table (Whippet V-80 separator, Sutton, Steele & Steele, Inc.). The raw DDGS was sieved into multiple streams using 10 mesh, 20 mesh and 40 mesh screens. The 10-20 mesh fraction and 20-40 mesh fraction were then run on the blower and the separator separately, using the same settings for air velocity in the range of 0.32 m/s to 3.06 m/s. A high protein fraction was achieved (37.13% db) for the 10-20 mesh fraction with an air velocity of 2.42 m/s by the blower. For the separator, using the same settings for airflow speed, the rate of eccentric shaft vibration, feedstock loading rate, side and end slopes, a high protein fraction was achieved (39.24% db) for the 10-20 mesh fraction with a range of the rate of eccentric shaft vibration from 350 rotation per minute to 500 rotation per minute. Another high protein fraction was also achieved (40.61% db) for the 20-40 mesh fraction with the same range of eccentric shaft vibration (350-500 r/min). As a result, good protein separation could be achieved by operating either the blower or the gravity table, although further study is required to optimize the separation efficiency.

Keywords:DDGS, fractionation, air classification, gravity table, protein, fiber

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1 Introduction

Distiller Dried Grains with Solubles (DDGS) is the main co-product of corn-based biofuel ethanol production, using the dry grind method.With the rapid growth of US ethanol industry in recent years (Schnepf and Yacobucci, 2013), the production of DDGS has been dramatically increased. Thus, the utilization of DDGS becomes more and more important. DDGS is a dry mix of particulate materials and is mainly composed of protein, fiber, and fat (Zhang and Rosentrater, 2013). With high protein and high fiber particles, DDGS can be divided into high protein and high fiber fractions to make it more valuable (RFA, 2012). A high protein fraction will have a greater value as a feed, especially for monogastric animals, such as swine, poultry, and fish (Belyea et al., 2004), and a high fiber fraction will have more potential for ruminant diets, corn fiber gum, or phytosterols (Singh et al., 2002). In addition, the cellulose within the fiber could be raw material for lignocellulose ethanol production (Kim et al., 2007).

Many efforts have been made to separate DDGS. One group found that simply sieving DDGS could lead to a fraction significantly enriched in protein and the other fraction significantly enriched in fiber (Wu and Stringfellow, 1986); and smallest DDGS particles tended to be rich in protein and low in fiber (Liu, 2008). Furthermore Liu (2009a) sieved four commercial samples of DDGS. The results of this research showed that as the particle size decreased, protein and ash contents increased, and total carbohydrate (CHO) decreased (Liu, 2008). Another research to separate DDGS into two fractions in terms of difference between protein and fiber was conducted by two groups. As densest DDGS particles tended to be rich in protein and low in fiber, both of the groups tried to use controlled velocity air streams to separate relatively less dense DDGS particles from the

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bulk of the DDGS (Liu, 2009b; Singh et al., 2002). But both of the results showed that only airstream fractionation of DDGS did not enhance the content in either protein or fiber. The reason was that airstream fractionation separated particles is based on terminal velocity rather than density (Bettge and Pomeranz, 1993). To improve this process and to make it effective, the difference between terminal velocities of two particles depends on the difference between their size and density, with the assumption that their shape and surface characteristics were the same (Garcia and Rosentrater, 2012). The two groups developed methods of sieving and then aspiration to separate protein and fiber (Liu, 2009b; Srinivasan et al., 2005). They did sieving and distributed several sets of fractions based on size and then with an air fractionation unit for each size distribution. As Srinivasan et al. (2009) designed an experiment to sieve DDGS at a rate of 0.25 kg/s (1 ton/h), which split DDGS into four fractions; the three largest fractions were then aspirated to separate fiber. Final results showed that nearly 12.4% by weight of DDGS was separated as fiber product, and two high protein products which have low fiber content were produced. In other words, the goal was achieved under an experimental environment. However, because of its machine capital (foursets of air aspirators) and small-scale production, this method may not be an efficient way that can make profit. Apart from that, an improved and simpler separation process using one air aspirator was developed (Garcia and Rosentrater, 2010). A mill was used in this process to narrow the particle size distribution of the oversize fraction. After sieving and milling the oversize DDGS, the "Milled oversize DDGS" was fed to the only one air aspirator and was separated into "Heavy DDGS" which contained more protein and "Light DDGS" which contained more fiber.

2Materials and methods

The DDGS used in the present study wereobtained from Lincolnway Energy, LLC (Nevada, Iowa). Samples were directly collected from the DDGS storage pile under the inspection of the ethanol plant. The DDGS was then stored in plastic tubes at room temperature (23 ± 1℃).

The sieving facility was composed of a screw feeder (Vibra Screw Incorporated, Totowa, New Jersey, U.S.A.) and a round sieving separator (LS18S333P3WC, Sweco, Division No FM-I, L.L.C., Florence, Kentucky, U.S.A.). The screens of the round sieving separator were chosen according to ANSI/ASAE S319.3 (ASABE, 2004), using U.S. sieve nos. 10 (2.000 mm), 20 (0.850 mm), 40 (0.425 mm), and Pan (<0.425 mm).

A laboratory-scale gravity table (Whippet V-80 separator, Sutton, Steele & Steele, Inc.) was also used. The side and end slopes of this gravity table were stationary, while the rate of eccentric shaft vibration could be adjusted. Three fractions (Light, Medium and Heavy) could be obtained from the gravity table.

A laboratory-scale cylindrical blower (Iowa blower, Figure1) was also used. The airflow of this blower was generated by a fan, which was driven by an electric motor. The airflow was blowing from bottom to top of the blower, and the velocity of the airflow could be adjusted. Two fractions (Light and Heavy) could be obtained from the blower.

All the fractions were analyzed by a NIR (Near Infrared Spectroscopy) product analyzer (Instalab 800, Dickey-John Corporation, Auburn, Illinois, U.S.A.). Protein content (% db), oil content (% db), fiber content (% db) and moisture content (%) were obtained for each fraction.

The laboratory-scale cylindrical blower is equipment that can separate DDGS into two fractions using airflow. While the laboratory-scale gravity table (Whippet V-80 separator, Sutton, Steele & Steele, Inc.) is a machine that combines a shake sieve and air aspirator together, which means the process of separating DDGS into high protein and high fiber fractions through the gravity table becomes more simple and easy to operate. The DDGS sample was first sieved into four fractions using 10 mesh, 20 mesh and 40 mesh screens. Two of the four fractions (10-20 mesh fraction and 20-40 mesh fraction) were then processed on the gravity table and the blower separately. NIR (Near

Infrared Spectroscopy) was then carried out on all the fractions to determine the nutrient content of each fraction.

2.1 Sieving process

The raw DDGS was first sieved by using 10-mesh and 40-mesh screens and fractions of over 10 (particle size: >2.000 mm), 10-40 (particle size: 0.425-2.000 mm) and through 40 (particle size: <0.425 mm) were collected. And the 10-40 fraction was then sieved by using 20-mesh (particle size: 0.850 mm) screen, and fractions of 10-20 (particle size: 0.850-2.000 mm) and 20-40 (particle size: 0.425-0.850 mm) were obtained. The NIR (Near Infrared Spectroscopy) test was then carried out on the two fractions to determine the nutrient content of each sample (Table 1).

2.2 Sieving combined with gravity table

The 10-20 (0.850-2.000 mm) fraction and the 20-40 (0.425-0.850 mm) fraction obtained from the sieving process were operated on the gravity table. The rate of eccentric shaft vibration of the gravity table was set at the range of 350 rotations per minute to 500 rotations per minute. Three samples (Light, Medium and Heavy) based on density were obtained separately for each 10-20 fraction and 20-40 fraction. Total six samples were obtained for both 10-20 and 20-40 fractions (Table 2). The NIR (Near Infrared Spectroscopy) test was then carried out on all the six samples to determine the nutrient content of each sample (Table 2).

2.3 Sieving combined with cylindrical blower

The 10-20 (0.850-2.000 mm) fraction and the 20-40 (0.425-0.850 mm) fraction obtained from the sieving process were operated on the cylindrical blower. The velocity of the airflow was set to 0.32 m/s, 1.54 m/s, 2.42 m/s, 2.85 m/s and 3.06 m/s, separately. Different samples based on density can be obtained from the blower. For the 10-20 (0.850-2.000 mm) fraction, one sample (heavy) was obtained at the airflow velocity of 1.54 m/s, two samples (light and heavy) were obtained at the airflow velocity of 2.42 m/s, one sample (light) was obtained separately at the airflow velocity of 2.85 m/s and 3.06 m/s. For the 20-40 (0.425-0.850 mm) fraction, one sample (heavy) was obtained separately at the airflow velocity of 0.32 m/s and 1.54 m/s, one sample (light) was obtained separately at the airflow velocity of 2.42 m/s, 2.85 m/s, and 3.06 m/s (Table 3). The NIR (Near Infrared Spectroscopy) test was then carried out on all the samples to determine the nutrient content of each sample (Table 3).

3 Results and discussion

3.1 Sieving combined with gravity table

For the laboratory-scale gravity table, for both 10-20 (0.850-2.000 mm) and 20-40 (0.425-0.850 mm) fractions, the moisture content decreased from light to heavy samples. The heavy samples of both the two fractions had the lowest moisture content. While compared withthe 10-20 (0.850-2.000 mm) fraction, the 20-40 (0.425-0.850 mm) fraction had lower moisture content at the same density (Table 2). Lower moisture content was obtained from heavier DDGS samples and smaller DDGS particle size. For the gravity table, for the heavy sample of the 10-20 fraction, moisture content decreased by 3.17%, for the heavy sample of the 20-40 fraction, moisture content decreased by 3.8% (Table 1 and Table 2).

Compared withthe research conducted by Zhang and Rosentrater (2013), in which lower moisture content was also obtained from heavier DDGS samples and smaller DDGS particle size, the highest moisture content among all the samples of the present study was roughly the same while the lowest moisture content among all the samples of present study was lower.

For both 10-20 (0.850-2.000 mm) and 20-40 (0.425-0.850 mm) fractions, the protein content increased from light to heavy samples. The heavy samples of both the two fractions had the highest protein content. While compared to the 10-20 (0.850-2.000 mm) fraction, the 20-40 (0.425-0.850 mm) fraction had higher protein content at the same density (Table 2). Higher protein content was obtained from heavier DDGS samples and smaller DDGS particle size. The most effective protein separation was obtained by the gravity table at the heavy sample of the 10-20 fraction, with protein content

increased by 9.09% d.b., and at the heavy sample of the 20-40 fraction, with protein content increased by 8.75% d.b. (Table 1 and Table 2).

Compared withthe research conducted by Zhang and Rosentrater (2013), in which higher protein content was also obtained from heavier DDGS samples and smaller DDGS particle size, the lowest protein content among all the samples of the present study was roughly the same, while the highest protein content among all the samples of the present study was higher. This means that the protein separation of this study was more effective. And the protein separation of this research was more effective than that of the research conducted by Wu and Stringfellow (1986).

For both 10-20 (0.850-2.000 mm) and 20-40 (0.425-0.850 mm) fractions, the oil content increased from light to heavy samples. The heavy samples of both fractions had the highest oil content. While compared withthe 10-20 (0.850-2.000 mm) fraction, the 20-40 (0.425-0.850 mm) fraction had slightly lower oil content at the same density (Table 2). Higher oil content was obtained from heavier DDGS samples. The most effective oil separation was obtained by the gravity table at the heavy sample of the 10-20 fraction, with oil content increased by 3.68% d.b., and at the heavy sample of the 20-40 fraction, with oil content increased by 1.5% d.b. (Table1 and Table 2).

Compared withthe research conducted by Zhang and Rosentrater (2013), in which higher oil content could also be obtained from heavier DDGS, the lowest oil content among all the samples of the present study was roughly the same, while the highest oil content among all the samples of the present study was lower.

For both 10-20 (0.850-2.000 mm) and 20-40 (0.425-0.850 mm) fractions, the fiber content remained roughly the same among all three different density samples (Table 2). While compared withthe 10-20 (0.850-2.000 mm) fraction, the 20-40 (0.425-0.850 mm) fraction had roughly the same fiber content at the same density (Table 2). As a result, there was no significant separation of fiber during the present study.

Compared withthe research conducted by Zhang and Rosentrater (2013), which did not obtain good separation for fiber, the present research was not effective on fiber separation as well. Which may illustrate that the sieving plus gravity table process was not a valid way to enhance the fiber content of DDGS.

3.2 Sieving combined with cylindrical blower

For the laboratory-scale cylindrical blower, for the 10-20 (0.850-2.000 mm) fraction, the moisture content decreased while the airflow velocity increased for both light and heavy fractions (Table 3). This was because the faster the airflow, the more water would be carried out from DDGS. And for both 10-20 and 20-40 fractions, the light samples had slightly less moisture content than the heavy samples (Table 3). And by comparing with the moisture content of the fractions after sieving process, the moisture content was reduced by the cylindrical blower.

Compared to the research conducted by Zhang and Rosentrater (2013), all the samples obtained from the present study had less moisture content. This illustrates that the moisture separation of this study was more effective.

For both 10-20 (0.850-2.000 mm) and 20-40 (0.425-0.850 mm) fractions, and for both light and heavy fractions, the protein content increased while the airflow velocity increased (Table 3). This was because the “light particles” that had low protein content would be carried out by the airflow and the “heavy particles” that were rich in protein would remain. For the same particle size, the heavy fraction had more protein content than the light fraction (Table 3). By comparing with the protein content of the fractions after sieving process, effective separation of protein could be obtained from the heavy sample at the airflow velocity of 2.42 m/s for the 10-20 fraction, and from the heavy sample at the airflow velocity of 1.54 m/s for the 20-40 fraction, with protein content increased by 6.98% db and 3.75% db (Table 1 and Table 3).

Compared to the elusive process developed by Srinivasan et al. (2005), which obtained protein separation with protein content of 41.2% d.b. for 0.85mm particle size at airflow velocity of 4.45 m/s, the separation of the present study was slightly less effective. However, the facility used in the present study was much simpler than that used in the elusive process.

For both 10-20 (0.850-2.000 mm) and 20-40 (0.425-0.850 mm) fractions, and for both light and heavy fractions, the oil content increased while the airflow velocity increased (Table 3). This was because the "light particles" that had low oil content would be carried out by the airflow, and the "heavy particles" which tended to be rich in oil would remain. For the same particle size, the heavy fraction had more oil content than the light fraction (Table 3). By comparing the oil content of the fractions after sieving process, effective separation of oil could be obtained from the heavy sample at the airflow velocity of 2.42 m/s for the 10-20 fraction, with oil content increased by 4.1% d.b. However, for the 20-40 fraction, there was not much oil separation (Table 1 and Table 3).

Compared to the elusieve process developed by Srinivasan et al. (2005), which obtained oil content of 16.4% d.b. for 0.85 mm particle size at airflow velocity of 5.24 m/s, the separation of the present study was slightly less effective. However, the facility used in the present study was much simpler than that used in the elusieve process.

For both 10-20 (0.850-2.000 mm) and 20-40 (0.425-0.850 mm) fractions, the fiber content remained roughly the same among all of the samples (Table 3). As a result, there was no significant separation of fiber in the present study.

Compared to the elusieve process developed by Srinivasan et al. (2005), which obtained effective separation of fiber, the present research was not effective for fiber separation. This might be due to facility limit, and illustrates that the cylindrical blower was not the ideal equipment to separate fiber.

3.3 Implications

The present study has demonstrated that sieving plus the gravity table process, and sieving plus the cylindrical blower process are both effective ways to separate DDGS into fractions with high protein content. Although the facilities used in this research were laboratory-scale and the feeding rates were very low, several sets of meaningful data have been discovered and are useful for further and larger scale studies. There are many reasons why ethanol plants may want to fractionate DDGS. Some of these include production of higher-protein coproduct feeds; others might be value-added uses for the fiber fraction, including additional fermentation for the production of additional ethanol.

4 Conclusions

Effective separation of protein could be obtained from both sieving plus gravity table process and the sieving plus the cylindrical blower process. For the laboratory-scale gravity table process, a high protein fraction was achieved (39.24% d.b.) for the 10-20 mesh (particle size of 0.850-2.000 mm) heavy fraction, as protein content increased by 9.09% d.b., and another high protein fraction was also achieved (40.61% d.b.) for the 20-40 mesh (particle size of 0.425-0.850 mm) heavy fraction, as protein content increased by 8.75% d.b., with a range of the rate of eccentric shaft vibration from 350 rotations per minute to 500 rotations per minute. For the cylindrical blower process, a high protein fraction was achieved (37.13% d.b.) for the 10-20 mesh (particle size of 0.850-2.000 mm) heavy fraction, as protein content increased by 6.98% d.b. with an air velocity of 2.42 m/s. As a result, for both gravity table process and cylindrical blower process, an efficient fractionation could be obtained via working with 10-20 mesh sample, and this particle size could be one of the optimal choice for the further and larger scale research.

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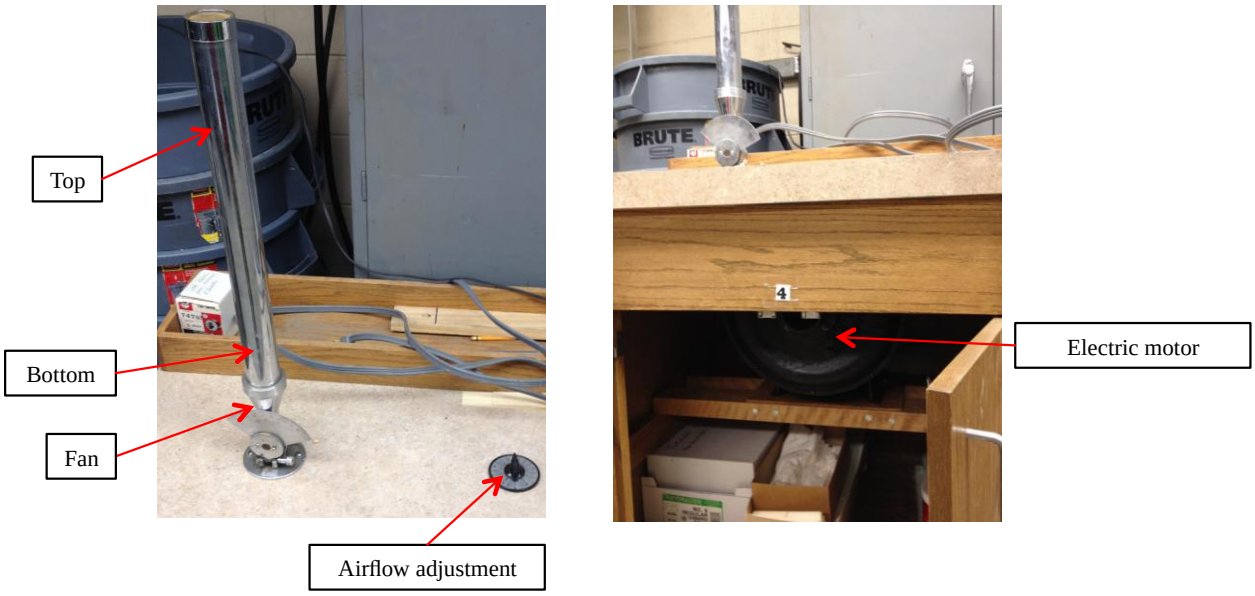

Figure 1The laboratory-scale cylindrical blower

Table 1Composition results for sieving process.

Process	Fractions	Moisture, %	Protein, % d.b.	Oil, % d.b.	Fiber, % d.b.
Sieving	10-20 (0.85-2.00 mm)	9.38	30.16	11.00	6.52
	20-40 (0.425-0.85 mm)	8.69	31.87	10.71	6.58

Table 2Composition resultsfor sieving plus gravity table process

Process	Fractions and samples		Moisture, %	Protein, % d.b.	Oil, % d.b.	Fiber, % d.b.
Sieving plus gravity table	10-20 (0.85-2.00mm)	Light	10.02	26.76	8.89	6.39
		Medium	7.37	34.52	11.66	6.53
		Heavy	6.21	39.24	14.39	6.57
	20-40 (0.425-0.85mm)	Light	9.46	28.17	9.43	6.49
		Medium	6.58	35.22	10.08	6.51
		Heavy	4.89	40.61	12.20	6.54

Table 3Composition resultsfor sieving plus the cylindrical blower process

Process	Fractions and samples		Airflow velocity, m/s	Moisture, %	Protein, % d.b.	Oil, % d.b.	Fiber, % d.b.
Sieving plus the cylindrical blower	10-20 (0.85-2.00mm)	Heavy	1.54	7.31	30.86	11.00	6.22
		Light	2.42	8.26	27.01	8.76	6.09
		Heavy	2.42	5.40	37.13	15.10	6.37
		Light	2.85	7.80	29.60	10.40	6.18
		Light	3.06	7.23	28.90	10.50	6.06
	20-40 (0.425-0.85mm)	Heavy	0.32	6.67	31.99	10.48	6.25
		Heavy	1.54	5.22	35.61	10.62	6.32
		Light	2.42	7.15	31.94	10.28	6.34
		Light	2.85	7.15	32.52	10.56	6.39
		Light	3.06	7.39	31.97	10.56	6.39

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